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STRATEGY OF VISUAL PROPRIOCEPTIVE CONTROL IN PATIENTS WITH INJURY TO THE ANTERIOR CRUCIATE LIGAMENT OF THE KNEE AND HEALTHY INDIVIDUALS (SOCCER PLAYERS)

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AUTHORS: Piontek T.[1], Ciemniewska-Gorzela K.[1], Szulc A.[2], Dudziński W.[3]

[1] Rehasport Clinic, Poznan, Poland Clinic of Peadiatric Orthopedic Surgery, UM Poznan, Poland
[2] Clinic of Peadiatric Orthopedic Surgery, UM Poznan, Poland
[3] Rehasport Clinic, Poznan, Poland

Reprint request to:
Kinga Ciemniewska-Gorzela
Rehasport Clinic, Poznan, Poland
Clinic of Peadiatric Orthopedic Surgery, UM Poznan, Poland
kinga_ciemniewska@poczta.onet.pl

ABSTRACT: Objective: Knee joint dysfunction resulting from injury to the anterior crucial ligament (ACL) is associated not only with mechanical joint instability but also with damage of ligamentous receptors responsible for the joint proprioception. It was found that disturbances of signals from the damaged joint produce disorders in movement perception and position of the analogous joint in the normal limb. This study is aimed at evaluating the control strategy in patients with an injury to the anterior crucial ligament.Design: Cohort study; Level of evidence, 3. Subjects/Patients- 84 men, aged 15 to 55 years (mean age 27 years) were included in this study. Methods- Patients were divided into two groups: those with unilateral injury to the ACL (33 patients) and a control group of healthy volunteers (soccer players; 51 men). Anterior crucial ligament damage was confirmed with arthroscopic knee joint examination in every patient. The way of visual proprioceptive control was assessed with both dynamic (DRT) and static (SRT) Riva tests standing on one leg. Tests were performed with the Delos Postural Proprioceptive System (Delos s.r.l., Corso Lecce, Torino, Italy) in the biomechanical evaluation laboratory at Rehasport Clinic in Poznań. Results: A statistically significant difference for deviations from the averaged axis in SRT (static Riva test) with closed eyes was found between the limb with a damaged ACL and the normal limb in the group of patients with injury to the ACL (p=0.006) and between the limb with a damaged ACL and normal limbs in healthy volunteers (p=0.022). A statistically significant difference for deviations from the averaged axis in SRT with closed eyes was also found between the dominant and non-dominant limb in healthy volunteers (p=0.013). No significant differences in the results of tests with open eyes were noted. Conclusions: The results of systems and their contribution to the visual proprioceptive control suggest an important role of the visual system in compensation of archeproprioceptive system disorders resulting from injury to the ACL. Clinical Relevance: Neurological deficits of proprioceptive perception, associated with injury to the ACL and affecting the balance, may be noted only in the results of tests performed with closed eyes.

KEY WORDS: ACL injury, proprioception, postural control

INTRODUCTION

Knee joint dysfunction resulting from injury to the anterior cruciate ligament (ACL) is associated with not only mechanical joint instability but also with damage of ligamentous receptors responsible for joint proprioception. It was found that disturbed signals from the damaged joint also produce erroneous proprioception of movement and position of the analogous joint in the counterpart, healthy limb [16-18,23,30]. Tests used so far to examine sense and joint position are inadequate to evaluate the effect of proprioception on maintenance of functional joint stability and produce contradictory results [2-4,6,12,19,30]. Therefore, the problem of proprioception and functional joint stability requires the development of other methods of evaluation than those used up to now.

Riva's concept, published in 2000, makes use of the knowledge of proprioception and its role in the maintenance of functional joint stability and enables its wider application in practice. This author introduced for the first time the concept of archeoproprioception. He also stressed the role of both conscious and unconscious proprioception [26-28]. According to Riva, archeoproprioception concerns the part of signals from peripheral proprioceptors that reach the oldest structures of the central nervous system (CNS) (spinal cord, mesencephalon, and cerebellum [especially the so-called archeocerebellum]). Information contained in these signals, reaching only CNS subcortical structures, remains unconscious. The term proprioception according to Riva's concept is reserved for a conscious component of the proprioceptive sensation. The majority of authors, including Riva, define this component as a special type of sense of touch, including the sense of both position and joint movements [26-28]. In the described concept, it is precisely this unconscious proprioception component (archeoproprioception) that is a base of proprioceptive reflexes necessary for functional joint stability. Studies have shown that during joint loading, neuromuscular reflexes that maintain joint stability are generated mainly in the spinal cord [14,29]. Evaluation of position sense in the joint and kinaesthesia do not provide adequate information on functioning of proprioceptive reflexes that seem to be responsible for the joint functional stability.

Riva assumes that inadequate posture control is always a sign of lower limb functional instability, even if its mechanical stability is maintained. To maintain balance and proper posture, signals generated not only in peripheral mechanoreceptors but also in the retina and vestibular labyrinth are integrated and analysed at various levels of the CNS. Thus, Riva distinguishes three information systems enabling posture control [26-28].

Archeoproprioceptive system – "intelligent", in which information from the large number of receptors located in the joints, muscles and ligaments may be transmitted at very high speed (about 80 to 120 $m \cdot s^{-1}$) to the nervous centres in the spinal cord and mesencephalon, where it is analysed and initiates an immediate reflex response from the muscles. This response is modified by the muscle spindle–muscle system. Because of this immediate reaction in the situation of the body balance loss, the archeoproprioceptive system is activated prior to other systems.

Visual control system – spatial head movement is associated with a shift of the retinal fixation point. The system of visual control detects such shifts and initiates muscular reflex reactions to restore the previous picture from the retina. Head vertical oscillations are of a few millimetres with open eyes. When the eyes are closed, their amplitude and frequency are increased. Visual control system activity improves precision of the archeoproprioceptive system in body posture control.

Vestibular control system – its action is mainly based on the vestibular labyrinth. This system is the most delayed in relation to other, more precise systems. Therefore, it is the last one enabled in extreme situations. It is activated when head movements are markedly accelerated or deviate from the axis while other systems are lacking or malfunctioning (archeoproprioceptive and visual control systems).

Riva, based on these observations, elaborated a method of body posture control evaluation, enabling one to determine which information system is prevailing in an individual in dynamic situations. Riva distinguished three ways (strategies) of postural control, using an appropriate equipment system on a dynamic basis (Riva dynamic test; DRT) and static assessment of posture maintenance (Riva static test; SRT) [26-28]. Visual proprioceptive control – the most subtle and precise way of posture control, based mainly on the archeoproprioceptive system. In this case, visual control serves to increase movement precision. The examined individual stands on one leg on an unstable platform with four degrees of freedom, with his arms joined behind the back. To maintain body balance, very quick ankle movements of low amplitude are made. The vestibular system is inactive at this moment and does not interfere in the subtle complicated motor behaviour based on the signals from the two remaining systems of information.

Disturbed visual proprioceptive control with compensation with upper limbs – the examined individual maintains a vertical posture standing on one leg on an unstable platform. To maintain body balance he/she uses ankle movements but also upper limb movements, which play a steering role in this situation. This way of control is used when archeoproprioceptive system functioning is disturbed. It decreases vestibular system interference in maintenance of body balance.

Vestibular control (emergency) – the least precise system of posture control, based on information received from the vestibular system. This control is activated only at significant head deflexion and its movements with high acceleration or delay. This control includes continuous trunk, hip, and upper limb movements and counter movements. The motor response produced by the vestibular system activity is usually excessive in relation to the forces disturbing balance. This excessive motor response, inadequate to the said biomechanical situation, makes balance maintenance on an unstable platform impossible during the test.

One of the most frequent injuries in athletes performing contact sports, e.g. football players, is damage to the anterior cruciate ligament (ACL). Such injury leads to knee joint instability and consequently to the development of early degenerative articular lesions. To prevent such lesions, reconstruction of the anterior cruciate ligament is performed. However, it turns out that proper mechanical stabilization of the knee joint is only one of the elements giving a chance of restoration of its normal function. Studies by several authors [1-3,5,7,15,21,22,24,25,28,32] show that there are at least three mechanisms leading to the development of knee joint instability (hereinafter "loss of knee joint function") following anterior cruciate ligament injury. Firstly, injury to the anterior cruciate ligament as a passive stabilizer of the knee joint leads to mechanical joint instability. Secondly, mechanoreceptors and free neuronal endings located in the ligament are destroyed (mainly in its attachments area), leading to disruption of the deep sensibility pathways transmitting information from the ligamentous receptors, which results in disordered coordination of muscles controlling the knee joint. Thirdly, increased erroneous mobility of the unstable knee joint generates altered reactions of mechanoreceptors in other articular structures and produces disordered information in the central nervous system (CNS), being a source of erroneous perception of both posture and movements of the injured joint. Such a situation may lead to neuromuscular coordination disorders in the knee joint and disturbed body posture and balance.

Some published studies on the effect of the visual system on balance maintenance show its significant or even superior character in relation to other systems [9,10,20]. O'Connel et al. showed in their work a marked effect of the visual system on maintenance of body balance in one-legged stance tests. They also proved that an increase in centre of gravity sway in one-legged stance tests with closed eyes concerns both examined normal subjects and patients with anterior cruciate ligament damage, but with no difference between these groups [23]. Vuillerma et al. showed a significant effect of vision on the compensation of proprioception deficits in balance maintenance resulting from fatigue of the calf triceps muscle [31]. These facts persuade us to analyse the results of functional tests in the context of visual compensation of other sensitivity deficits, including proprioception, for the purpose of proper interpretation.

In the work, we assume that injury to the anterior cruciate ligament due to interruption of afferent pathways transmitting proprioceptive signals from the ligament receptors significantly disturbs the archeoproprioceptive information system and postural control, which can be visualized in both dynamic and static Riva tests. We also assume that the visual system plays an important role in compensation of disorders in the archeoproprioceptive system resulting from anterior cruciate ligament injury.

This study is aimed at evaluating and comparing results of visual proprioceptive control assessment in patients with chronic anterior cruciate ligament injury and in healthy individuals serving as a control group, so as to evaluate visual system participation in the compensation of disorders in the archeoproprioceptive system to maintain optimal body balance in space.

MATERIALS AND METHODS

The study was performed with the approval of the local research ethics committee, in accordance with the Declaration of Helsinki, and with the informed consent of all subjects (Agreement of Ethical Committee in UM in Poznań no. 267/08).

Participants

The study group included eighty-four men aged between 15 and 55 years (mean age 27 years). The subjects were divided into two groups: Group A: control group of healthy volunteers (football players) (51 men). Group B: patients with unilateral injury to the anterior cruciate ligament (33 men). Diagnosis was confirmed by knee joint arthroscopy in every case.

Group B was further divided into subgroup B1 for the healthy limb and B2 for the ACL deficient knee.

Intervention and Testing Protocol

Evaluation of postural control manner

Visual proprioceptive control was evaluated with both dynamic (DRT) and static (SRT) Riva tests standing on one leg. Delos (Delos s.r.l. Corso Lecce, Torino, Italy) postural control system was used to perform the tests in the Biomechanical Assessment Laboratory at Rehasport Clinic in Poznań.

In SRT, the subject stands on one leg on a stable surface and tries to keep balance during a set period of time. A "posture sensor" attached to the subject's chest sends information on trunk sway. Additional information is generated by the "postural assistant" – a metal bar with an infrared sensor over it. In case of balance loss, the subject grips the bar and a signal is registered in the data analyser (computer with special software) together with data from the "posture sensor". The test is performed with open and closed eyes (exclusion of the visual postural control system), enabling disorders in the visual and vestibular systems to be detected (Fig. 1).

The dynamic Riva test is performed standing on one leg on the platform with four degrees of freedom (mobility in frontal and sagittal plane) and trying to maintain balance. The data analyser simultaneously assesses the data from the posture sensor and platform sways. Therefore, evaluation of the visual proprioceptive postural control is possible (Fig. 2).

Each postural evaluation, in accordance with the recommendations of Le Clair and Riach 11, consisted in a stabilometric static double-leg stance (bipedal test) and a stabilometric static single-leg stance

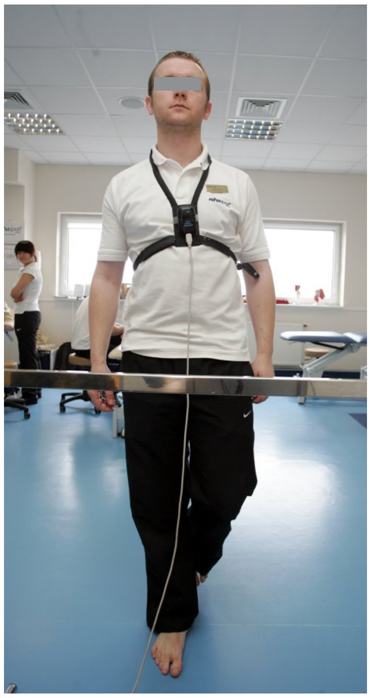

FIG. 1. STATIC RIVA TEST STANDING ON ONE LEG – SCHEME OF THE TEST

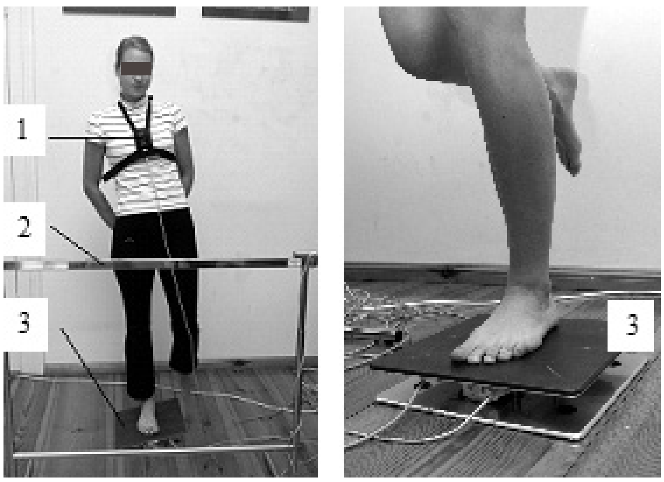

FIG. 2. SCHEME OF THE TEST: 1 – VERTICAL CONTROLLER (DVC) – POSTURAL CONTROL READER; 2 – POSTURAL ASSISTANT (DPA) – SUPPORTING BAR WITH INFRARED SENSOR; 3 – EQUILIBRIUM BOARD (DEB) – ELECTRONIC ROCKING-ROLLING BOARD.

(monopedal test). The bipedal test consists in 2 attempts, the first with eyes open (EO) and the second with eyes closed (EC). Each test lasted 20 seconds, with the subjects standing barefoot on the ground with arms resting at their sides. The monopedal test consists in 4 attempts, the first two with EO, one with weight on the left foot on the ground and the other foot relaxed but not touching the ground, the second with the weight on the right foot on the ground. The last two tests are carried out with EC, alternating leaning, as in the first two tests. Each test lasted 20 seconds, with the subjects standing barefoot on the ground, in an upright position, with arms at his/her side. The Delos Postural Proprioceptive System® (DPPS), used in performing these stabilometric tests instead of the other system with platforms for vertical forces, makes use of an angular speed detector – the Delos Vertical Controller (DVC) – oval shaped, 7 X 4.5 X 2.5 cm in size, connected to a computer. The DVC, applied in correspondence to the sternum, by means of elastic bandaging, exactly defines, following instantaneous calibration of the software, the COM of the subject under examination. With this instrument it is possible to test both the bipedal and monopedal stance and to record the variations in the position of the COM, with a sensitivity of 0.1 degrees. For each test performed, the software defines the closeness of the angle from the median x-y axis, the mean x-y distance from the COM, the mean x-y speed and the mean x-y inversion frequency. Furthermore, the novel DPPS system consisting of an adaptable steel structure for hand support, the Delos Postural Assistant (DPA), equipped with an infra-red sensor, which is also connected to the computer. The DPA is placed in front of the patient so that he/she, during the examination, can easily rest his/her hands, in the event he/she risks falling. This leaning bar, by avoiding this risk, is able to record the frequency and duration of the corrective events that the subject has to perform in order to maintain the position assumed. As already pointed out, the equilibrium of a subject who is standing immobile, in a bipedal or monopedal position, is maintained with EO by the activity of the visual, vestibular and proprioceptive strategies. In the event there is a defect in one or more of these systems, the subject is forced to make use of the DPA in order to avoid the risk of falling. The greater the number of times and the longer the time the patient relies on the bar, the worse his/her balance becomes. Whether or not the DPA is used offers a series of indispensable parameters for evaluation of a subject's posture. One of these parameters is the precautionary strategy which expresses in percentage just how much the equilibrium of a subject is related to the duration and frequency of the leaning of their hands on the DPA. This pathological postural strategy is directly proportional to the risk of falling. Absence of this strategy indicates that the subject is able to maintain a correct posture employing the normal physiological strategies – visual, vestibular and proprioceptive strategies. With the use of the DPA bar, in performing the monopedal test, it is possible to obtain further useful information, such as the maximum time without leaning and the mean time of leaning.

Statistical analyses

Statistical analysis of the results of visual proprioceptive postural control was made for the absolute value of the best result among performed tests of men–stable surface–platform system instability and an index of vertical postural control.

Data collected during visual proprioceptive postural control tests, according to reference values of static (SRT) and dynamic (DRT) Riva tests, had to be integrated for analytical purposes.

The results of the following scales were analysed: deviations from the mean SRT axes in visual control and resultant of SRT mean axes with closed eyes, deviations from the mean DRT axes, risk of falling down, instability of men–platform system and index of vertical postural control.

Kruskal-Wallis and Mann-Whitney non-parametric tests were used for statistical analysis. A critical alpha level of $p<0.05$ was chosen for statistical significance.

RESULTS

Significance of differences in studied parameters

An analysis with post-hoc tests was performed for parameters that differed significantly within study groups. Statistically significant differences were found only for deviations from the averaged axis in SRT with closed eyes, out of all analysed parameters. Tables 1, 2, 3, and 4 show the levels of significance for differences between the groups. Statistically significant values are shadowed.

DISCUSSION

Patients with ACL deficient knees use various adaptive mechanisms to maintain functional stability of the knee joint during variable ac-

TABLE 1. SIGNIFICANCE LEVELS FOR DIFFERENCES BETWEEN THE GROUPS

	Group A	Group B1	Group B2
Group A		0.064	0.004
Group B1	0.064		1.000
Group B2	0.004	1.000	

TABLE 2. SIGNIFICANCE OF DIFFERENCE IN RESULTS FOR GROUP B; COMPARISON BETWEEN GROUPS B1 AND B2

	Group B1	Group B2	Significance level
Deviations from the averaged axis in SRT with open eyes	5.59 ± 1.25	5.48 ± 1.25	ns
Deviations from the averaged axis in SRT with closed eyes	3.75 ± 1.89	3.47 ± 1.92	p<0.01
Deviations from the averaged axis in DRT	3.74 ± 1.27	3.68 ± 1.18	ns
Instability of man-platform system	6.69 ± 3.28	6.77 ± 2.75	ns
Vertical posture maintenance controller	47.78 ± 12.52	46.28 ± 11.82	ns

Note: The values are mean ± standard deviation; ns – not statistically significant

TABLE 3. SIGNIFICANCE OF DIFFERENCES BETWEEN HEALTHY LIMB IN GROUP B AND GROUP A

	Group B1	Group A	Significance level
Deviations from the averaged axis in SRT with open eyes	5.59 ± 1.25	5.70 ± 0.50	ns
Deviations from the averaged axis in SRT with closed eyes	3.75 ± 1.89	4.50 ± 1.38	p<0.05
Deviations from the averaged axis in DRT	3.74 ± 1.27	4.18 ± 0.71	ns
Instability of man-platform system	6.69 ± 3.28	6.44 ± 3.12	ns
Vertical posture maintenance controller	47.78 ± 12.52	46.57 ± 14.71	ns

Note: The values are mean ± standard deviation; ns – not statistically significant

TABLE 4. SIGNIFICANCE OF DIFFERENCES BETWEEN DOMINANT AND NON-DOMINANT LIMB IN GROUP A

	Dominant	Non-dominant	Significance level
Deviations from the averaged axis in SRT with open eyes	5.71 ± 0.59	5.58 ± 1.23	ns
Deviations from the averaged axis in SRT with closed eyes	4.52 ± 1.33	3.77 ± 1.91	p<0.05
Deviations from the averaged axis in DRT	4.19 ± 0.69	3.73 ± 1.25	ns
Instability of man-platform system	6.45 ± 3.17	6.67 ± 3.32	ns
Vertical posture maintenance controller	46.61 ± 13.98	47.80 ± 12.58	ns

Note: The values are mean ± standard deviation; ns – not statistically significant

tivities. The lack of a uniform scheme of these mechanisms indicates an enormous potential of the human body which enables the use of several adaptive mechanisms of different schemes in case of injury to one and the same structure for each individual. One important adaptive mechanism compensating for the lack of proprioceptive signals from the injured ACL for balance maintenance is the visual control system. Earlier studies by O'Connell et al. confirmed it [23]. The lack of statistically significant differences in the results of tests with open eyes in our study, i.e. between the ACL deficient limb and the healthy one as well as between the ACL deficient limb and the group of healthy volunteers, and simultaneously clear statistically significant differences between above-mentioned groups in tests with closed eyes, confirm a marked influence of the visual control system on body balance maintenance in case of injured ACL. O'Connell et al. did not find statistically significant differences in the centre of gravity sways between patients with ACL injury and the control group of healthy subjects. However, in our study, similarly to Gauffin et al. and Zatterstrom et al., such differences are clearly seen [8,33]. This may result from the fact that the studies by O'Connell et al. involved simple tools, which are not so sensitive as Riva tests or other dynamic tests [23]. Our study confirmed the hypotheses by Hrysomallis et al. and O'Connell et al. on higher usability of dynamic tests on an unstable platform in detection of dysfunction in body balance control resulting from ACL injury [13,23].

Due to such a strong and still unclear mechanism of the visual compensation of deficits in the archeoproprioceptive system in the control of body balance resulting from injury, e.g. to the ligaments or muscles, even very good results of the visual postural control tests should be interpreted cautiously.

Tests performed in this study in the control group of healthy subjects showed statistically significant differences in SRT with closed eyes between the dominant and non-dominant limb. Better results were obtained for the dominant limb. Similar significant differences for the supporting (non-dominant) and manipulating (dominant) limb were obtained by Guillou et al., who tested football players [11]. However, these authors used tests for assessment of balance under visual control. We did not find statistically significant differences in our results of tests with open eyes. These divergences stress a necessity of cautious interpretation of tests assessing postural control and balance. We think that the results of such tests should be interpreted in association with data from the anamnesis, including questions about vision defects and type of training (symmetrical or asymmetrical).

CONCLUSIONS

We may conclude that in the general assessment of visual proprioceptive control, subjects from the control group represented a level similar to that in patients with ACL injury. This indicates a high capability to compensate for proprioception deficits after ACL injury. The results of assessment of particular systems and their contribution to the general visual proprioceptive control strategy indicate a significant role of the visual control system in compensation of archeoproprioceptive system dysfunction resulting from ACL injury. Marked divergences in the results of tests assessing postural control and balance, reported in the literature, and no possibility to distinguish deficits resulting from ACL injury and difference of results between the dominant and non-dominant limb, require cautious interpretation of these results together with data from the anamnesis.

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